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Investigation on the Quality of Prolonged Storage of Packaged Water Commonly Produced in North Central, Nigeria

Fatai Olayiwola OKEOLA[1], Taofiqat Omotayo ABU[1], Aminat Aderonke MOHAMMED[1]*, Muyiwa Michael OROSUN[2], Abdullahi BABA[1], Mariam Bolanle ADEBOJE[1]

[1]University of Ilorin, Department of Industrial Chemistry, Kwara State, Nigeria.
[2]University of Ilorin, Department of Physics, Kwara State, Nigeria.

Abstract: This study investigated the effects of prolonged storage conditions on the physicochemical parameter, toxic metals, microbial loads, and health risks assessment of randomly selected three brands of sachet and bottled water in North Central, Nigeria. One hundred eighty samples of water brands (sachet and bottled) were collected from 10 different factories and were grouped into three. They were analyzed immediately (initial), being exposed to mild sunlight (stored with a container) and exposed to intense sunlight (stored without a container) conditions for six weeks. The results of the physicochemical parameters (sachet and bottle) were within the limits set by the World Health Organization (WHO) and the Standard Organization of Nigeria (SON). While the results of heavy metals analysis for both sachet and bottled water recorded 0.15 - 0.51 mg/L (0.10 mg/L , 0.05 mg/L), 0.13 - 0.38 mg/L (0.015 mg/L, 0.01 mg/L) and 0.55 - 1.11 mg/L (0.03 mg/L, 0.3 mg/L) for Chromium (Cr), Lead (Pb) and Iron (Fe) respectively, as compared to the permissible limits (values in the bracket for each heavy metals) set by WHO and SON. The microbial analysis results ranged between 6.58 - 124.51 Cfu/100 mL, 0.52 - 37.56 Cfu/100 mL, 0.07 - 5.00 Cfu/100 mL, 0 - 2.07 Cfu/100 mL for Total Bacteria Count (TBC), Total Coliform Count (TCC), Faecal Coliform Count (FCC) and Total Fungal Count (TFC) respectively, which showed no effective quality control system. Incremental lifetime cancer risk (ILCR) assessment revealed a carcinogenic health risk to the populace drinking this water. The study concludes that water stored under sunlight for a long period is not good for human consumption and therefore adequate monitoring by the appropriate agencies is emphasized.

Keywords: Sunlight, Ilorin, sachet water, storage condition, microbial analysis.

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***Corresponding author. E-mail:** mohammed.aa@unilorin.edu.ng.

1. INTRODUCTION

Water is an essential liquid for human day-to-day activities. It is a basic need for human existence required to maintain personal hygiene, prevention of diseases, and food production (1-3). Waterfalls such as rain can be found in lakes and rivers which are the primary sources of fresh water for agriculture, human consumption, and industrial uses (4, 5). Portable water is a source of water that is properly treated and showed a minute amount of contaminants such as toxic metals, microorganisms, nitrates, sulfates among others (5, 6, 7). Various natural processes (such as wind deposition, weathering of rocks, soil leaching, and biological processes) and anthropogenic activities (such as agricultural run-off, mining, recreational activities, industrial and domestic sewage) all contribute to the release of contaminants into water bodies, which poses serious health risks like malnutrition, gastrointestinal diseases, slowing nutrient absorption, and disrupting the endocrine system, among others (5, 8, 9).

According to WHO/UNICEF (10), over 844 million people in most developing countries lack adequate good water supply as a result of an increase in population and urbanization, and this paves way for packaged water as a fast-growing business in most developing countries. The water business is very lucrative due to the rate at which consumers buy this packaged water (sachet and bottled). Sachet and bottled water can come from a variety of sources, including well, water from a protected spring, or water from a public water supply. However, there is a great risk associated with water produced in an unsafe and unhygienic environment (11, 12). Many scholars have reported that sachet and bottled water are the major drivers for the transmission of pathogens and toxic metals into the body (13, 14, 15, 16), and these often resulted in several health challenges among children and infants, with noticeable effects including water-borne diseases like diarrhea, typhoid, cholera, hepatitis, and dysentery among others (17, 18, 19, 20).

Similarly, several researchers reported that the main problems associated with the production of sachet and bottled water in Nigeria include the way they were handled during the production process, ways in which distributors and vendors transported the packaged water, and how the packaged water was stored for several weeks before they were sold (21, 22). In most of the cities and towns in Nigeria, sachet and bottled water are often stored and exposed to direct sunlight without adequate knowledge of the effect of the quality of this packaged water on the populace buying them. To the best of our knowledge, the rate at which packaged water (sachet and bottled) production increases in the Ilorin metropolis (North Central, Nigeria) is becoming so alarming. However, there is a need for a routine investigation on the quality of prolonged storage of both sachet and bottled water exposed to sunlight under different storage conditions.

This research aimed to determine the physicochemical, heavy metal concentrations, microbial analysis, and human health risk assessment of some sachet and bottled water sold within North Central, Nigeria, and compared the results obtained with the permissible limits of the Standard Organization of Nigeria (SON) and World Health Organization (WHO).

2. MATERIAL AND METHODS

2.1. Description of the Study Area

The Kwara State of Nigeria belongs to North Central Nigeria. There are sixteen Local Government Areas in Kwara State, with the capital city at Ilorin. The Local Government Area in Kwara State includes Ilorin East, Ilorin South, Ilorin West, Moro, Kaima, Asa, Offa, Ekiti, and Edu among others. The Ilorin West Local Government lies between latitude 4° 28 E, 8° 34 N and longitude 4° 35 E, 8° 24 as shown in Figure 1. According to National Population Census 2006, the population of Ilorin West People is 364,666 with a total landscape of 105 square kilometers.

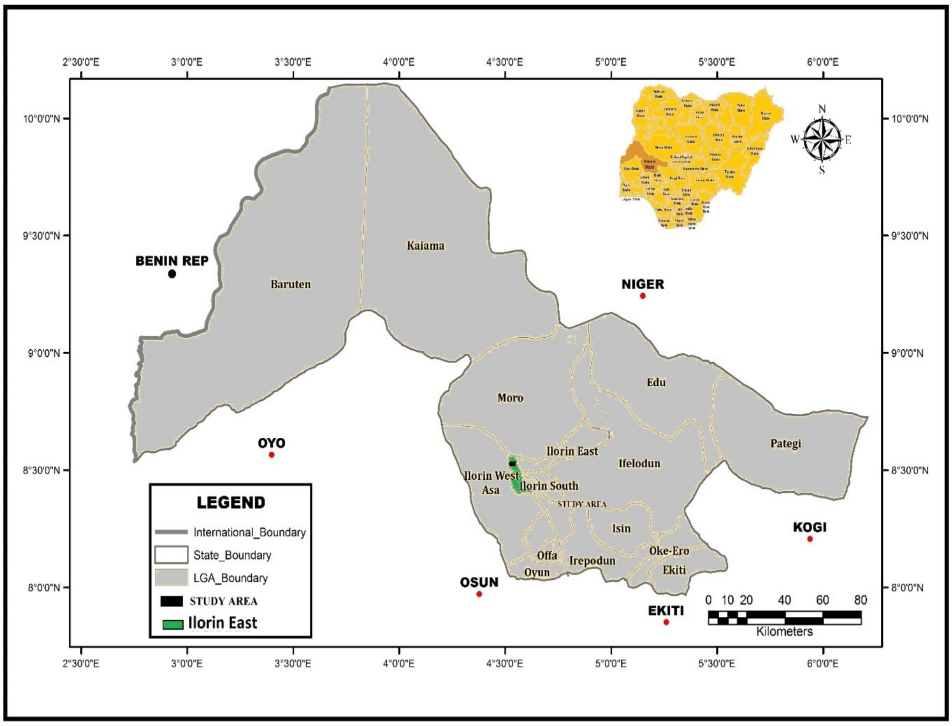

Figure 1: Showing Map of Ilorin West Local Government Area, Kwara State, Nigeria.

2.2. Sample Collection and Preparation

Three brands of sachet and bottled water were collected from three factories. Thirty samples each of sachet and bottled were procured from each factory amounting to a total of 180 samples (90 sachets and 90 bottled water). For each brand, the samples were divided into groups A, B, and C. Group A represents 20 water samples (10 sachet and 10 bottles) analyzed immediately (initial) after being purchased from the factories. Group B represents 20 water samples stored in a container and exposed to sunlight for six weeks (mild condition) before analysis. And Group C represents 20 water samples stored and exposed directly to the sunlight without a container for six weeks (intense condition) before analysis.

2.3. Reagents and Pretreatment

Milli-Q water, HNO_3 (65%), and HCl (37%) analytical grades were purchased from Merck Darmstadt, Germany. All glassware used for this study was soaked in 1M HNO_3 for 24 hours and rinsed severally with distilled water.

2.4. Physico-chemical Parameters

The pH was measured using a pH meter Ino Lab Tech 7310 digital multimeter, which gives a direct value of pH, and it was calibrated with buffer solutions (pH 4 and 7). A thermometer was used to measure the temperature of the water samples in situ. Electrical conductivity (EC) and total dissolved solids (TDS) were determined by the HANNA Digital multimeter and it was calibrated with potassium chloride solution. Alkalinity, hardness, chloride, and calcium contents were determined titrimetrically. The concentration of magnesium contents was determined by subtracting the concentrations of calcium from total hardness. sulfate contents were determined turbidimetrically and Nitrate contents were determined by the Brucine method (23). Water samples were taken from each brand in triplicates for the analysis.

2.5. Determination of Toxic Metals

A 50 mL of each water sample (sachet and bottled) was digested by aqua regia method of digestion using HNO_3/HCl in 1:3 ratio and was later analyzed for the presence of toxic metals, namely chromium (Cr), lead (Pb), and iron (Fe) in triplicates using Atomic Absorption Spectrophotometer (AAS-Buck Scientific Model 210 VGP, USA).

2.6. Quality Control Determination

Calibration curves were plotted for all analyzed elements (Cr, Pb, and Fe) which were used to measure the absorbance value for the blank and working standard solution (which was prepared from a stock standard of each metal using Milli- Q water) to determine the concentrations of toxic metals in the digested samples. The detection limits of the instrument range from 0.005 – 0.040 mg/L as shown in Table 1. Blank determination was done by weighing 2 mL of HNO_3 in a beaker with 6 mL of HCl added, and the mixture was heated in the water bath for 40 minutes and cooled. The mixture was transferred to a 50 mL standard flask and make-up to the mark with distilled water. The experiment was repeated three times and then analyzed using Atomic Absorption Spectrophotometer. A recovery study was done by spiking 10 mL of heavy metal standards (Cr, Pb, and Fe) to already analyzed water samples and re-analyzed (A). A known amount of water samples (sachet and bottled) was left un-spiked (Z) and analyzed using AAS. The percentage recovery study (R.S%) was evaluated using the equation 1 (24)

$$R.S\% = \frac{A-Z}{10} \quad (1)$$

Table 1: Detection limits of the instrument.

Elements	Instrument detection limits (mg/L)
Cr	0.005
Pb	0.040
Fe	0.007

2.7. Microbiological Parameters

Total bacterial count (TBC), total coliform count (TCC), and total fungal count were also determined in each of the water samples using multiple tube fermentation and membrane filtration methods described by (25).

2.8. Human Health Risk Assessment

The association between the concentration of the toxic metals and their apparent risk to human health is generally appraised by the human health risk assessment models established by the USEPA (26, 27, 28) and UNC (29). This technique is accessible using the risk assessment information system (RAIS) USEPA (26) and the toxicological profiles presented by the United State Environmental Protection Agency's Integrated Risk Information System (IRIS) (30, 31, 32), in collaboration with the United State Agency for Toxic Substances and Disease Registry – Toxicological profiles (33). In this current research, the risk evaluation of the toxic elements (Cr, Pb and Fe) was initiated by primarily evaluating the chronic daily intake (CDI) of each of the metals through the possible exposure pathways (in this case, ingestion pathway).

For the ingestion pathway of exposure, the chronic daily intake (CDI) (mg/L/day) was evaluated by the following equation 2 USEPA (34).

$$ADI_{\text{ing-water}} = \frac{Cw \times IngRw \times EF \times ED}{BW \times AT} \quad (2)$$

Where C_w is the concentration of the given heavy metal in the sampled drinking water, BW is bodyweight of the exposed person (70 kg), ED is the lifetime exposure period (average life expectancy of Nigerians is 55 years), EF is the exposure frequency (365 days/year), AT is the period through which the dose is averaged (ED x 365 days) and $IngR_w$ is the ingestion rate of the drinking waters (2 L/day).

2.9. The Carcinogenic and Non-Carcinogenic Risk Assessment

The calculated chronic daily intake (CDI) in proportion to oral reference dose (RfD_{oral}) of the selected toxic metals branded as target Hazard Quotient (HQ), is generally utilized to highlight the severity of the non-carcinogenic risks. The hazard quotient is called by the formula in equation 3 as described by USEPA (26);

$$HQ=\frac{ADI}{RfD} \quad (3)$$

where CDI is the chronic daily intake of a given toxic constituent and RfD is the persistent reference dose for the element i.e. for the Cr, Fe, and Pb, we have 3.0E-03, 9.0E-02, 3.5E-03 mg/L-day (34). If the HQ > 1, however, there is an increased probability of unfavorable health effects to the exposed populace. Conversely, if HQ < 1 subsequently there is no possibility of negative health effects (35).

The hazard index (HI) is the sum of the HQ calculated using Equation 4

$$HI=\sum HQ \quad (4)$$

According to the risk classification system assembled by the International Agency for Research on Cancer (IARC) and WHO, among the toxic metals analyzed in this study, Pb and Cr were human carcinogens, and their carcinogenic slope factors are 8.5E-03 and 0.5 $(mg/L/day)^{-1}$ respectively (30). The carcinogenic risk estimation gives an index of risk or possibility of an aimed people developing cancer of several types as a result of the ingestion of the carcinogens in the drinking water over a projected lifetime. Incremental Lifetime Cancer Risk (ILCR**)** presents the carcinogenic risk calculated using equation 5 (30, 36).

$$ILCR = ADI \times SF \quad (5)$$

Where CDI (mg/L/day) and SF $(mg/L/day)^{-1}$ are the mean daily consumption of the toxic metals and the carcinogenic gradient factor. Cancer risk higher than 1E-04 is considered high as they pose a higher cancer threat while values below 1E-06 are assumed not to cause any cancer risk to the populace; the suitable range is flanked by 1E-04 and 1E-06.

3. RESULTS AND DISCUSSION

The recovery study (R.S%) was done to ascertain the analytical method employed in the determination of toxic metals in the water samples (sachet and bottled water). The R.S% estimated ranges between 85.2 - 102.8% as illustrated in Table 2.

Table 2: Recovery study of toxic metals in the water samples.

Water Samples	Toxic metals Analyzed	Amount Spiked	Amount Un-spiked	R.S%
Sachet	Cr	62.55	54.03	85.2
	Pb	34.39	25.06	93.3
	Fe	58.50	48.22	102.8
Bottled	Cr	48.73	39.02	97.1
	Pb	74.95	65.31	96.4
	Fe	29.54	20.65	88.9

The physicochemical parameters, toxic metals, and microbiological analysis examined show considerable variations in the sachet and bottled water samples analyzed as shown in Figures 2 - 6. The pH value of all the brands of water analyzed ranged from 6.56 - 8.22. The pH of the water sample was recorded between 6.65 - 7.28 and 7.78 - 8.22 for bottled and sachet water respectively (Figure 2a & b). This is similar to the report by previous researchers (37, 38, 39). Water samples stored at mild sunlight exposure (Group 2) ranged from 6.79 - 8.01 and 6.62 - 8.00 for intense sunlight exposure (Group 3). Water samples in Brand 3 recorded the highest pH value of 8.22 and 7.28 (Group 1) for sachet and bottled water respectively. An increase in the pH values of water can lead to an increase in the bacteria population (10). An increase in the pH values could be due to the different modes of storage as shown in Figure 2. The pH values of all the water brands were within the recommended pH range WHO (40), SON (41), and WHO (42) as shown in Table 3. The mean temperature value ranged from 28.61 - 30.64 ^{0}C for all brand samples analyzed (Figure 2). Samples of water analyzed immediately (initial) after being purchased from the factories ranged between 28.70 - 29.03 ^{0}C (Group 1). While samples of water stored and exposed to mild and intense sunlight exposure ranged between 29.82 - 30.64 ^{0}C (Group 2 and 3) as shown in Figure 2. This is similar to the previous report elsewhere (43). An increase in the warmness of an environment favours the growth of microorganisms and this can affect the taste and odour of the water samples (44). Turbidity values in all the brands of water samples analyzed (bottled and sachet) were found to be less than 5 NTU for all the water samples exposed to different storage conditions. The turbidity values recorded were all within acceptable limits of 5 NTU (41, 42) as shown in Table 3. Conductivity values in all the brands of water samples (sachet and bottled) ranged from 45.33 - 160.12 µS/cm. Water samples analyzed immediately (Group 1) ranged from 89.9 - 146.90 µS/cm, while water samples exposed to mild (Group 2) and intense sunlight (Group 3) ranged from 49.55 - 131.30 µS/cm and 53.94 - 147.20 µS/cm respectively. This is similar to the previous study reported in the literature (45, 46). Brands 1 and 3 (Group 1) recorded the lowest results in both sachet and bottled water. The TDS concentrations of the water samples in all the brands ranged from 22.03 - 81.00 mg/L as shown in Figure 2. Water samples analyzed immediately (Group 1) recorded 30.00 - 81.00 mg/L for both sachet and bottled water brands. A similar result was reported elsewhere (46). While water samples (sachet and bottled) stored under mild (Group 2) and intense sunlight exposure (Group 3) ranged from 22.03 - 65.76 mg/L and 23.51 - 73.60 mg/L respectively (Figure 2). TDS was found to be within the permissible limit of 500 mg/L as shown in Table 3.

The total hardness concentration (TH) ranged from 20.05 - 80.40 mg/L for all brands of water analyzed. The hardness values recorded were all within WHO-acceptable limits (100 mg/L). TH of the water samples (sachet and bottled) stored under mild sunlight exposure (Group 2) ranged from 20.05 - 76.11 mg/L (Figure 3). While those stored under intense sunlight conditions (Group 3) ranged from 24.13 - 80.40 mg/L. A similar result was obtained elsewhere (44). The results obtained in this study showed an increase in the value of hardness when subjected to both mild and intense sunlight conditions. Chloride concentration ranged from 0.43 - 41.83 mg/L for all brands of water stored under different conditions. The highest chloride concentration value of 41.83 mg/L was recorded in Brand 3 for sachet water analyzed (Figure 3a), and the least was recorded in the bottled water in Brand 1 (1.03 mg/L), (Figure 3b). The Calcium (Ca) concentration ranged from 11.33 - 54.08 mg/L for all the brands of water samples (initial, mild, and intense) for both sachet and bottled water. This result followed a similar trend to the previous study (46). The highest value of calcium was recorded in Brand 3 (54.08 mg/L) and the lowest was recorded in Brand 2 (11.33 mg/L) for mild and initial sunlight exposure respectively. The concentration of calcium was found to be lower than the permissible limit set by WHO as indicated in Table 3. The concentration of magnesium in all the water samples analyzed ranged from 6.02 - 30.22 mg/L in all brands of water used for this study. The results obtained were found to be higher than the previous reports elsewhere (47, 48). A higher concentration of magnesium is known to cause water hardness, and cathartic and diuretic effects in the human body (49). The concentration of sulfate was found to be lower in bottled water (0.01 - 0.03 mg/L) than the values obtained in sachet water (0.01 - 0.15 mg/L). The concentration of sulfate reported in this study is lower than the values obtained in previous literature (50, 51). The concentration of sulfate was found to be lower than the permissible limit (100 mg). Alkalinity values ranged from 2.16 - 8.32 mg/L for all the water brand samples investigated. It was observed that there is a variation in the concentration of the water samples exposed to various storage conditions (mild and intense sunlight exposure). High values of Alkalinity were reported in similar work (50, 51). The values of Nitrate obtained in water samples ranged from 2.11 - 8.47 mg/L. The Nitrate value recorded ranged from 3.9 - 7.0 mg/L and 2.11 - 8.47 mg/L in sachet (Figure 3a) and bottled (Figure 3b) water respectively. This is similar to the previous literature (50, 51). The Nitrate contents in all the brands of water investigated were below the permissible limits by WHO (40), SON (41) and WHO (42) as shown in Table 3.

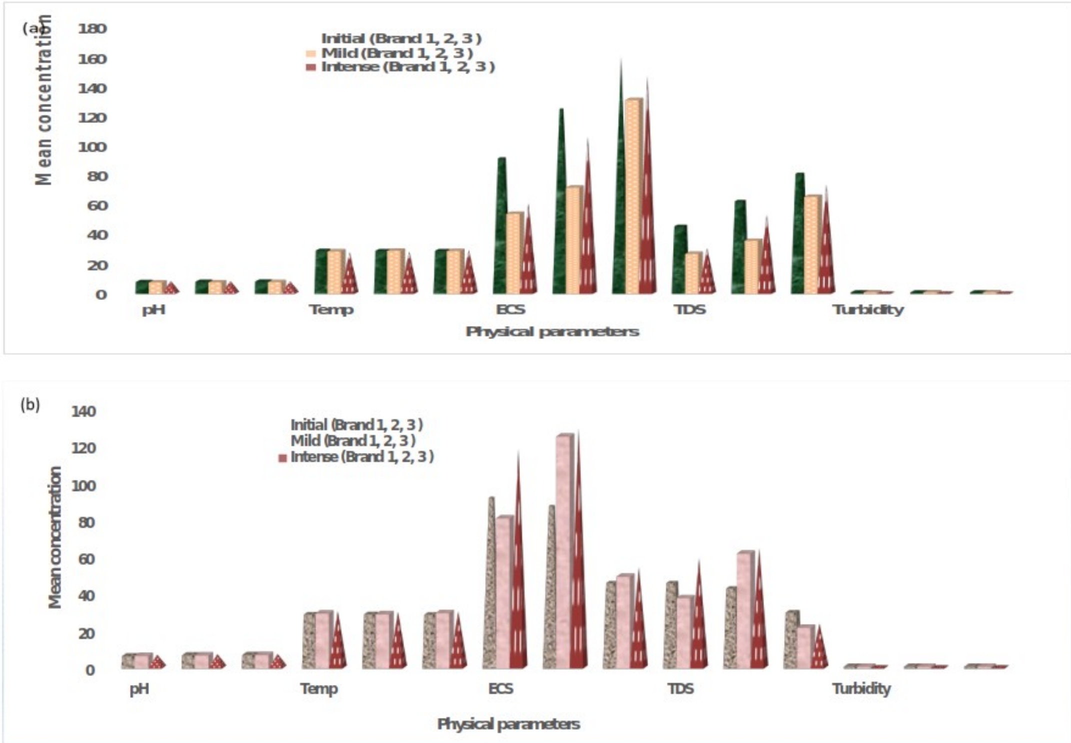

Figure 2: Showing Variation of Physical Parameters in (a) sachet water and (b) bottled water groups.

Table 3: Permissible limits set by WHO and SON.

Parameter	**Maximum Permissible limits** WHO[a]	SON[b]
pH	6.5-8.5	6.5-8.5
Temperature	35-40 °C	Ambient
Electrical Conductivity	1.0 ms/cm	1000 µs/cm
Total Dissolved Solids	500 mg/L	500 mg/L
Turbidity	5 NTU	5 NTU
Total Hardness	100 mg/L	150 mg/L
Calcium	200 mg/L	
Magnesium	150 mg/L	-
Chloride	100 mg/L	250 mg/L
Sulfate	250 mg/L	100 mg/L
Nitrate	10 mg/L	50 mg/L
Alkalinity	200 mg/L	NA
Chromium	0.10 mg/L	0.05 mg/L
Lead	0.015 mg/L	0.01 mg/L
Iron	0.03 mg/L	0.3 mg/L
Total bacterial count	100 cfu/mL	NA
Total Coliform Count	NA	NA
Faecal Coliform Count	Negative	NA
Total Fungal Count	1-130 cfu/L	NA

* WHO[a] (2006, 2011) *SON[b] (2007) *NA= Not available *NA=Not Available

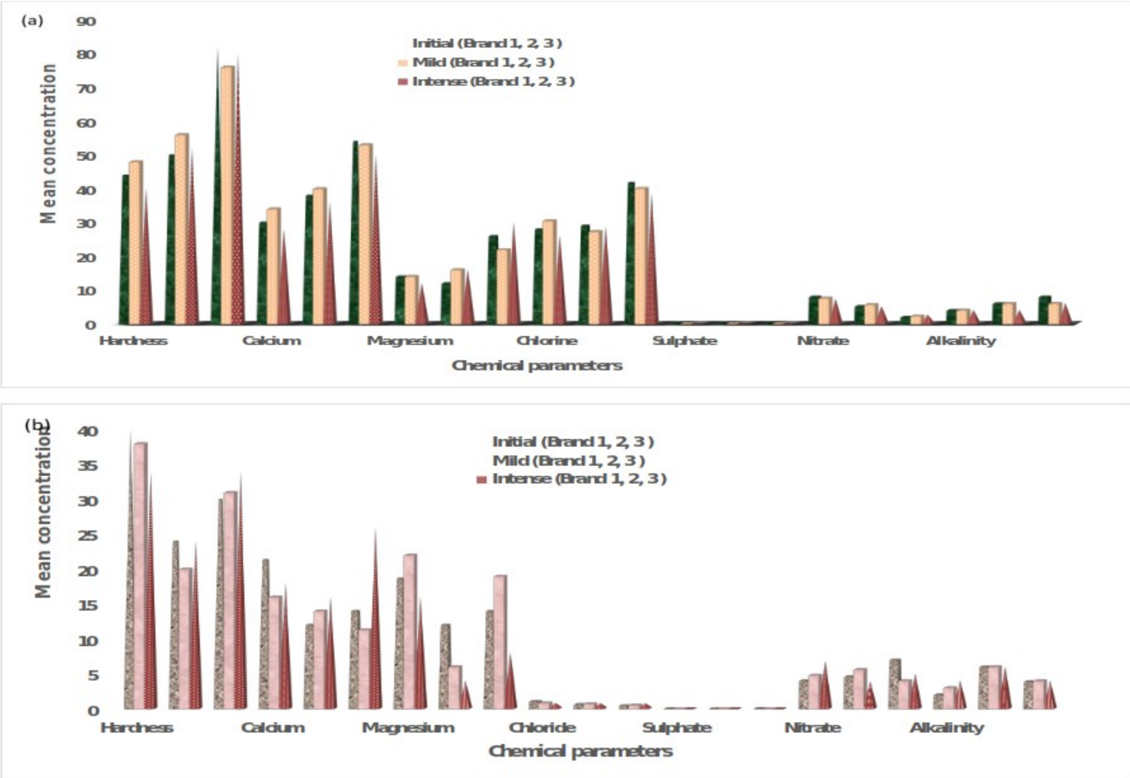

Figure 3: Showing Variation of Chemical Parameters in (a) sachet water and (b) bottled water groups.

Chromium (Cr) value ranged from 0.15 - 0.51 mg/L for all the water samples analyzed under different conditions of storage which was found to be higher than the permissible limit set by both SON and WHO (Table 3). Cr contents ranged from 0.14 - 0.22 mg/L and 0.16 - 0.51 mg/L) in both sachet (Figure 4a) and bottled water samples (Figure 4b) respectively. This result is well corroborated by the previous researcher (52). Cr at a very high concentration is known to be toxic to humans and can cause cancer. Lead (Pb) value ranged from 0.13 - 0.38 mg/L for all the brands of water samples. The presence of Lead in high concentrations can damage nervous connections (especially in young children), cause blood, and brain disorders. Pb is also known to be a possible human carcinogen (53). The concentration of Pb in all samples from the different brands was found to be higher than the acceptable limits of 0.015 mg/L and 0.01 mg/L set by WHO (40) and SON (41) as shown in Table 2. The mean concentrations of Iron (Fe) obtained in all the water samples ranged from 0.55 - 1.11 mg/L. The results obtained in this study are similar to the results earlier reported in the literature (44, 54). The highest concentration of Fe was recorded in Brand 2 (sachet) and the least concentration in Brand 1 (bottled) for intense and mild sunlight exposure respectively. The Fe concentrations ranged from 0.55 - 1.06 mg/L and 0.69 - 1.11 mg/L for water samples stored under mild and intense sunlight conditions respectively (Figure 4). There is a variation in the values of all the parameters checked on all the brands of water samples stored under different conditions (mild and intense sunlight exposure). This could be a result of the geochemistry of the soil in which water is drilled, water treatment methods employed, ways of handling and transportation of the packaged water (sachet and bottled) from the vendors to final consumers.

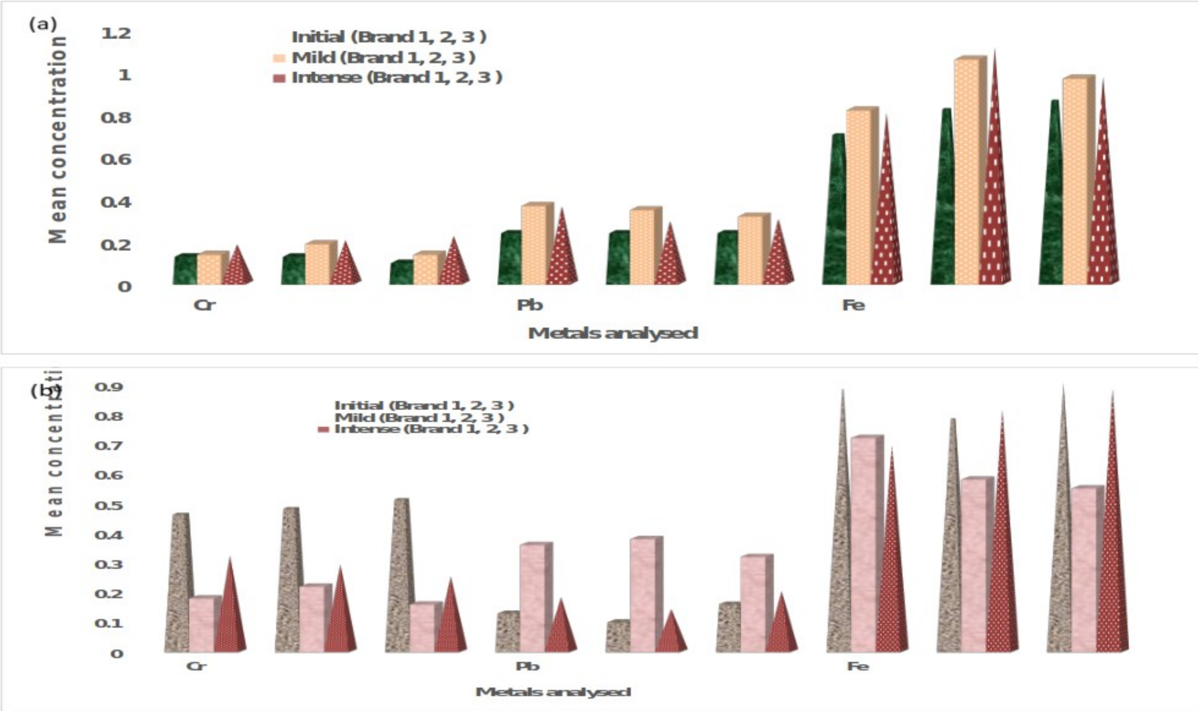

Figure 4: Showing variation of metals analyzed in (a) sachet water and (b) bottled water groups.

The value of Total bacteria count (TBC) ranged from 6.58 - 124.51 Cfu/100 mL for all the water samples (Figure 5). TBC values recorded for water samples stored under mild and intense sunlight condition ranged from 14.51 - 124.51 Cfu/100 mL and 21.55 - 84.05 Cfu/100 mL, respectively. This follows a similar trend to the previous reports elsewhere (46, 55). This is because a warm environment favors the growth of bacteria. The TBC found in all the water samples was found to be higher than permissible limits by WHO (40), SON (41), and WHO (42) as shown in Table 3. The value of Total coliform count (TCC) ranged from 0.52 - 37.56 Cfu/100 mL for all the water samples (Figure 5). The TCC values ranged from 0.52 - 5.0 Cfu/100 mL and 1.05 - 37.5 Cfu/100 mL in both bottled and sachet water, respectively. The result obtained in this study is higher than the previous report in the assessment of the quality of water before and after storage in the Nyankpala Community of the Tolon-Kumbungu District, Ghana (46) and lower than the previously reported research from different scholars (56, 57, 58). Brand A water sample showed no TCC value in bottled water as compared to other brands of water samples which were above the limits set by WHO (33) and (34). Water samples analyzed immediately recorded Faecal coliform count (FCC) that ranged between 0.09 - 0.27 Cfu/100 mL. The FCC values ranged from 0.53 - 5.10 Cfu/100 mL and 0.51 - 1.08 Cfu/100 mL in both sachet (Figure 5a) and bottled water (Figure 5b) respectively for mild and intense storage conditions. Total fungi count (TFC) found in all the sachet water samples ranged from 0 - 2.07 Cfu/100 mL which are lower than the permissible limit by WHO and SON. TFC analysis showed that water analyzed at zero-day (initial) has 0 Cfu/100 mL for all the brands. While those exposed to mild sunlight exposure recorded 0.64 - 2.07 Cfu/100 mL and samples stored under intense sunlight exposure recorded 0.52 - 1.11 Cfu/100 mL which are below the limits set by WHO (40) and SON (41). The results obtained in this study showed that as the temperature increases, microbial loads (TBC, TCC, FCC and TFC) also increase for water samples exposed to mild and intense storage conditions.

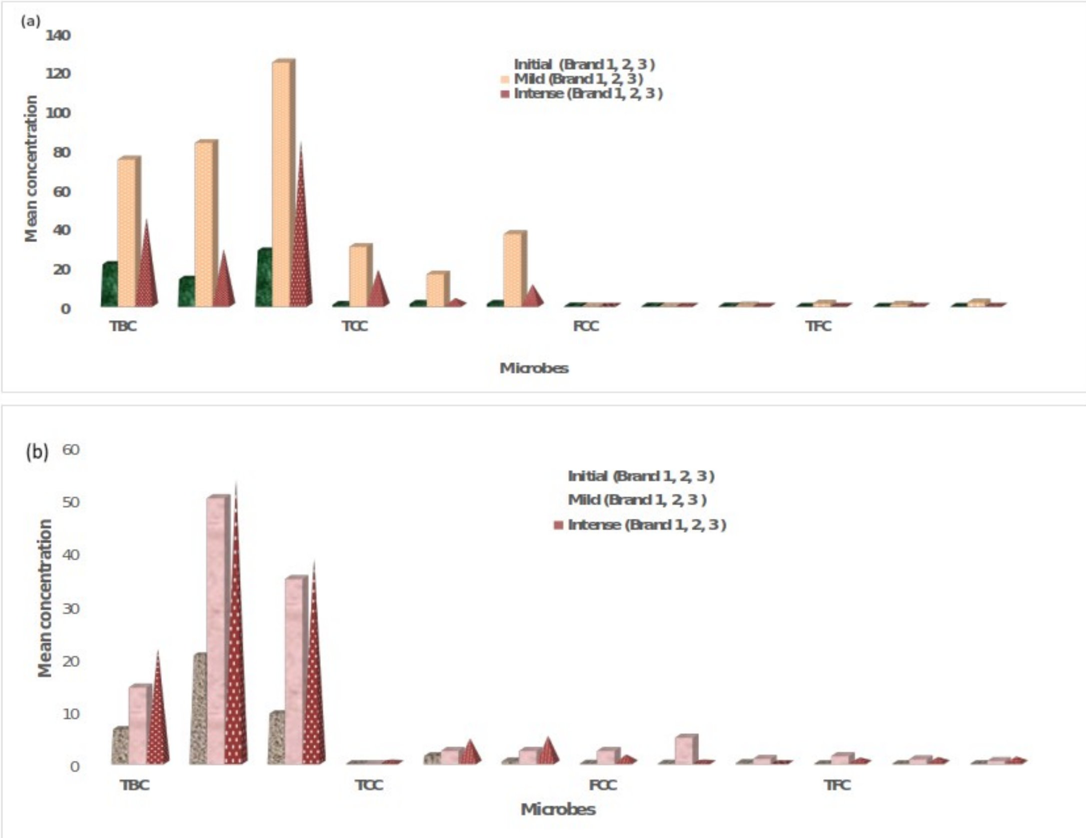

Figure 5: Showing the variation of (a) microbial analysis in sachet water and (b) bottled water groups.

The Hazard Quotient (HQ) estimated for all the toxic metals in all the three (3) water groups (i.e. initial, mild and intense conditions) are within the recommended safe limit (<1)) set by USEPA (34). The total Hazard Index (HI) for the initial, mild, and intense condition groups are 0.8373, 0.6620, and 0.6664 respectively for bottled water and 0.1874, 0.2446, and 0.2512 respectively for sachet water (Figure 6). The results obtained in this study imply that the general populaces are not in any danger of non-carcinogenic health effects of these toxic metals. While the mean HI value for the initial conditioning appears to be greater than the mild and intense conditioning category for the bottled water, the reverse is the case with sachet water where the mean HI value for the intense conditioning is greatest.

The Incremental Lifetime Cancer Risk (ILCR) was estimated and the mean values for the initial, mild and intense condition groups are 8.86E-4, 1.16E-3, and 1.47E-3 respectively for the sachet water (Figure 6a), 6.94E-03, 2.75E-03, and 4.14E-03 respectively for the bottled water (Figure 6b), and with Cr contributing most to the cancer risk in both cases. Because cancer risks greater than 1.00E-4 are considered high since they pose a higher cancer risk, and values below 1.00E-6 are considered not to pose any cancer risk to humans, it follows that the cancer risks are high for the three (3) water groups (i.e. initial, mild and intense condition) for both sachet and bottled water. Since the result reveals values of ILCR that are 100% higher than the recommended limit, the general populace is in danger of carcinogenic health effects. However, it is noteworthy that the reported carcinogenic and non-carcinogenic risk values in this study may be undervalued because the appraisals did not capture intakes from other metals like arsenic, cadmium, and nickel, among others, and the exposure parameters (i.e. EF, AT, BW and ED) used were adopted from USEPA (28), so might not ineludibly represent a typical Nigerian case.

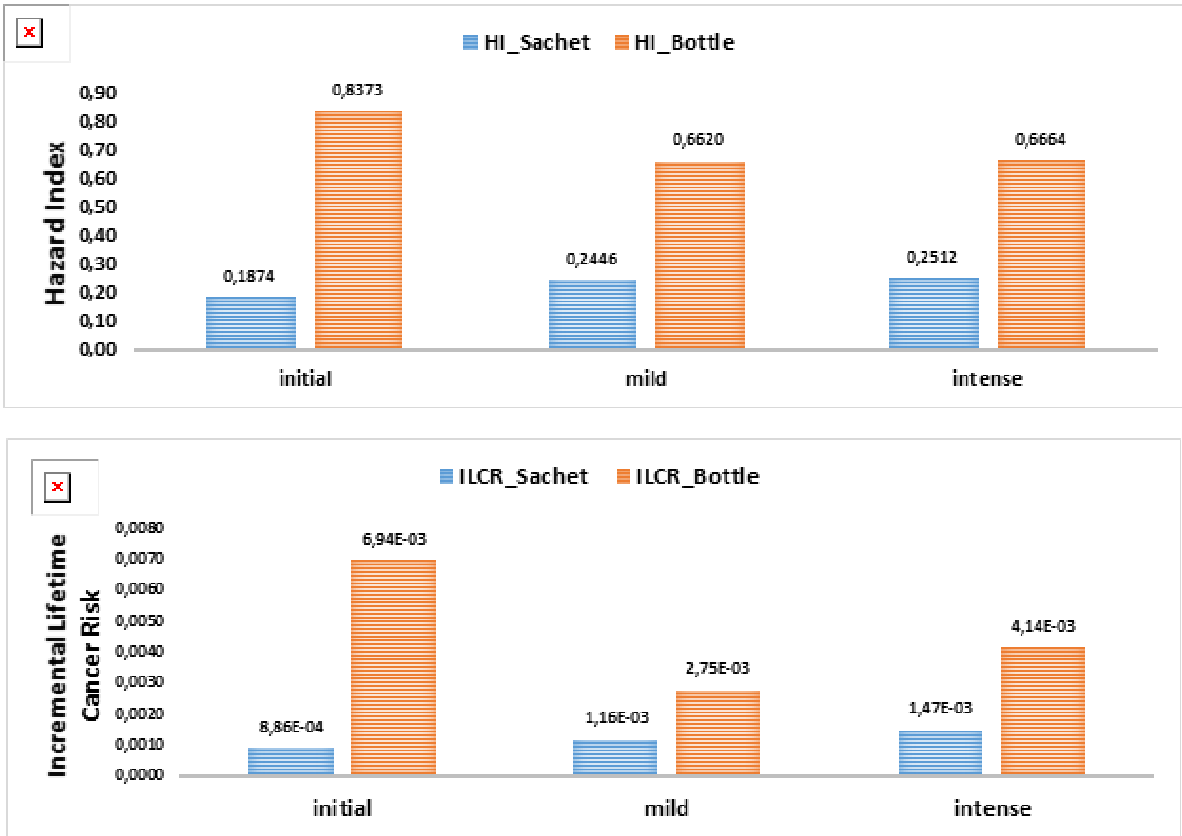

Figure 6: Showing (a) Hazard Index and (b) Incremental Lifetime Cancer Risk for all the water groups

4. CONCLUSION

Water is a liquid needed at all times for several human activities. This study revealed that the samples taken to the laboratory were operating within the WHO limits for physicochemical guidelines for drinking water regardless of the mode of storage. Heavy metal concentrations were found to be above the limits set by WHO/SON in all the water samples analyzed. While the corresponding carcinogenic risks revealed values that are higher than the recommended safety range, the non-carcinogenic risk assessment reveals values within the acceptable limits. Thus, the study reveals that the general populace is in danger of carcinogenic health effects. The appearance of microbial loads (TBC, TCC, FCC, and TFC) in all the water analyzed revealed prolonged storage of water has led to an increase in microbial growth. Therefore, this study concluded that water samples exposed to prolong sunlight are not safe for human consumption. However, proper monitoring and compliance with drinking water standards are adequately required by various agencies.

5. CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

6. ACKNOWLEDGMENTS

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